Community-based Improvement of the Digital Bathymetric Model LEPLAC in Southeastern Brazil

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Abstract

This work presents the process of updating the LEPLAC[1] Digital Bathymetric Model (DBM) in the southeastern margin of Brazil, following the Recommended Workflow for Analysis of Bathymetric Surfaces used by the Brazilian Navy. As a result of the application of comparative quantitative and qualitative analysis between the reference data and the LEPLAC DBM, two regions of possible artifacts were identified, both in the shelf break. Such results were communicated to the Brazilian Navy, which confirmed its existence and updated the depth values in these locations. The updated version of the LEPLAC DBM were, then, reanalyzed. A Difference Surface Map was built between the two versions of the LEPLAC DBM, in order to spatialize the improvements done by the surface updating procedure. Also, the same quantitative and qualitative analysis were applied to the SRTM15+ V 2.0 DBM, in order to compare the quantitative and qualitative indicators of both bathymetric surfaces. Lastly, a Difference Surface Map between the updated LEPLAC DBM and the SRTM15+ V 2.0 were built, in order to quantify the advances brought to the national bathymetry by the LEPLAC DBM in the study area. The digital surfaces were evaluated by univariate and bivariate statistical techniques, regression analysis, Difference Surface Maps, topographic profile graphs and histograms. The reference data consists of 2778 km of linear bathymetric data from multi-beam and single-beam echosounders, ranging from depths from 10 to 2500 m, in addition to two DBM from multi-beam bathymetry on the Santos Basin slope (Mount Alpha Crucis and Pockmarks Fields). These data were collected by N/Oc Alpha Crucis in surveys of the University of São Paulo and the Federal University of Santa Catarina and are independent of the model confection.

[1]Levantamento da Plataforma Continental Brasileira (Brazilian Continental Shelf Survey Program)

Introduction

The LEPLAC Digital Bathymetric Model (DBM) is the newest regional digital bathymetric surface available for the Atlantic Ocean. Published in 2019, it revolutionized the understanding of the geomorphological diversity and compartmentation of the Brazilian margin seabed. Its construction was due to the need to suit the regulations contained in Article 76 of the United Nations Division for Ocean Affairs and Law of the Sea (UNCLOS, 1994 and United Nations, 1999), in order to support the Brazilian Submission for the extension of the continental shelf beyond 200 nautical miles (Alberoni et al., 2019).

The DBM is the result of more than two decades of extensive and rigorous work in the acquisition and quality control of acoustic data from various sources (mono and multi-beam echosounders; bathymetry derived from seismic) by the Directorate of Hydrography and Navigation (DHN) of the Brazilian Navy, under the LEPLAC. In total, more than 770.000 km of bathymetric data were collected across the entire Brazilian continental margin, from the country's northern border with French Guiana to its lower border with Uruguay. In addition to the aforementioned data, acoustic data provided by Petrobras, Brazilian National Agency of Oil, Gas and Biocombustibles (ANP) and several Brazilian and foreign institutions were used, as well as data from public databases from international institutions such as the National Geophysical Data Center (NGDC), GEODAS and the National Oceanic and Atmospheric Administration (NOAA). In regions where acoustic data is scarce (mainly in deep water) depth values from the DBM SRTM30+ were used (LEPLAC, 2015; Mohriak and Torres 2017; Alberoni et al., 2019).

The motivation for this work arose from the knowledge of the Recommended Workflow of Bathymetric Surface Analysis (Florentino et al., 2019). The “Recommended Workflow” suggests that, having access to the original input bathymetric data, after the comparative evaluation of regional DBMs against reference data, the “Bathymetric Surface Update” should be done. As suggested by the author and presented by Weatherall et al. (2015), updating bathymetric grids is a common practice aimed at enriching information and improving the DBM in use. The “Recommended Workflow” is used to update the LEPLAC surface by the Navy since its launch, as new data is acquired and validated by DHN.

This work presents the update of the LEPLAC DBM by applying the “Recommended Workflow” of Bathymetric Surface Analysis by joint action between the scientific community (Federal University of Santa Catarina and Oceanographic Institute of São Paulo University) and the

DHN. Two spurious data regions, named "Artifact 1" and "Artifact 2", were identified in the platform break. The existence of the artifacts was communicated to LEPLAC team, which confirmed their existence and updated the depth values in these regions. Then, the updated LEPLAC surface was re-evaluated.

Method

Recommended Workflow for Analysis of Bathymetric Surfaces

The methodology used to evaluate the bathymetric surfaces in this work is an adaptation of the “Recommended Workflow” of Regional Bathymetric Surface Analysis, proposed by Florentino et al. (2019) (Figure 1). Overall, this workflow uses quantitative and qualitative tools to assess regional digital surfaces against reference data. The workflow implies that, after evaluating and interpreting the results found and having access to the original incoming bathymetric data, the bathymetric surface under test should be updated. Afterwards the surface is updated, the workflow recommends that it should be re-evaluated by the same tools. As a way to quantify the changes resulting from the DBM update, the author suggests the creation of a Difference Surface Map between the original DBM and the updated DBM. In this work, in addition to the steps mentioned, a Bathymetric Difference Map between the updated LEPLAC DBM and the SRTM15+ V 2.0 DBM was generated. The objective of this last step is to quantify the advances brought by the creation of the LEPLAC DBM in the study area.

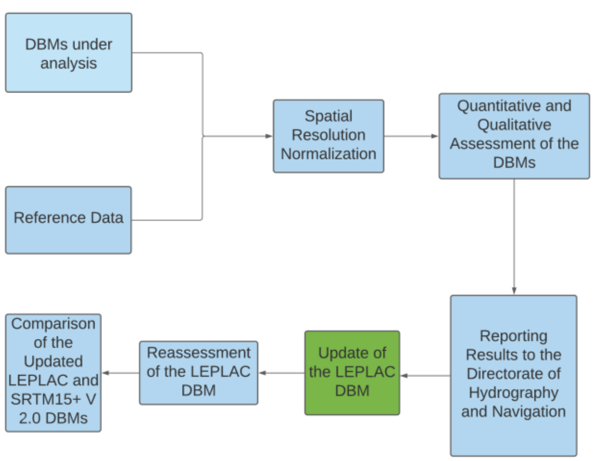

Figure 1 - Adapted Recommended Workflow for Analysis of Bathymetric Surfaces. Blue boxes represent the steps executed by the scientific community (Universidade Federal de Santa Catarina and Oceanographic Institute of University of São Paulo). Green box represents the step taken by the LEPLAC team.

Quantitative and Qualitative Analysis Tools

The analysis undertaken are summarized below.

1. Statistical Summary and Histograms

Important inferences can be made about the adherence of Digital Bathymetric Models to reference data from the comparison of their statistical summaries (Olea, 2009; Mukherjee et al. 2012; De Silveira et al. 2014; Florentino et al. 2019). In this work, descriptive statistics (maximum, minimum, mean, median, mode, standard deviation and vertical Root Mean Square deviation) of the discrepancies between the analyzed DBM and the reference bathymetric data were computed and compared. A multiseries plot are also presented for better visualization of the results.

2. Regression Analysis and Calculation of Correlation Coefficient

Regression analysis and calculation of Spearman's correlation coefficient are bivariate statistical that measure the statistical dependence (or adherence) between an independent variable "x" and a dependent variable "y", resulting in a linear mathematical model of association between the variables (Trauth, 2015; Bussab & Morettin, 2017).. In this work, such analyzes were applied to measure the linear dependence between the DBM under test and the reference bathymetric data. Although useful and widely disseminated in the literature, care must be taken when using these statistical tools. It should be considered that these are only preliminary indicators of the straightness with which two variables are related (Trauth, 2015).

3. Vertical Uncertainty Map

This step consisted of locating on a map the magnitude and spatial distribution of vertical uncertainties between the digital surfaces under test and the reference data. It was chosen to use the module of percentages related to the depths of the reference data to quantify the uncertainties. Thus, the uncertainty map represents the adherence of the analyzed pixels of the DBM to the reference data, in percentage. The representation of discrepancies in magnitude (meters) is less interesting, since an error of 10 m at a real depth of 20 m represents a difference of 50%, resulting in a very wrong estimate of reality. The same error of 10 m at a depth of 2000 m represents 0.5%, resulting in a depth estimate two orders of magnitude closer to reality.

4. Bathymetric Profile Graphs

With the application of the technique, it is possible to visually compare the adhesion of the modeled surfaces to the reference data, as well as the correlation of the DBMs and reference data with each other. According to Florentino et al. (2019), the comparison can be made visually, by direct measurements on the profiles arranged in the same graph, or even by calculating the areas below and above the reference profile compared to the other profiles. For this work, the topographic profiles were compared only visually and by direct measurements on profiles arranged in the same graph, since the other applied DBM analysis tools provide enough material for proper evaluation of the DBMs.

5. Difference Surface Maps

As mentioned before, the Difference Surface Maps were generated in two moments. First, it was made to quantify the changes in the LEPLAC DBM arising from the surface update after applying the analysis tools. At the end of the study, another Difference Surface Map was generated, this time aiming to quantify and spatially localize the advances brought to Brazilian bathymetry by the launch of the LEPLAC DBM for the study area.

Reference Data

In order to carry out the comparative analyses, 2778 km of linear data from multi- and single-beam echosounders were used, ranging from bathymetric elevations from 10 to 2500 m, in addition to two DBM from multi-beam bathymetry on the slope of the Santos Basin (Mount Alpha Crucis and Campos de Pockmarks, published in de Mahiques et al., 2017 and Maly et al., 2019) (Figure 2). These data were collected by N/Oc Alpha Crucis in suverys from the University of São Paulo and the Federal University of Santa Catarina and are independent of the LEPLAC surface production.

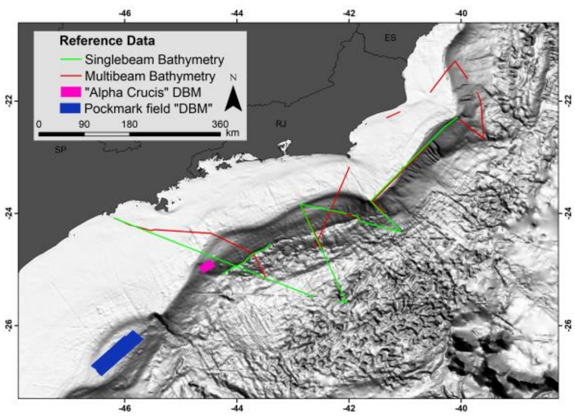

Figure 2 - Location Map of the Reference Data.

To apply the analysis tools 1, 2 and 3, the spatial resolutions of the DBM (Table 1) under test and the reference data were normalized, according to Marks et al. (2011) and Abramova (2012). The need for this step is based on the assumption that each pixel under analysis of the DBM were compared to only one (1) measure of each reference data. Likewise, for the comparison of results found for the different bathymetric surfaces analyzed to make sense, these must be applied to corresponding locations in all DBM. For this purpose, the data with the highest spatial resolution were subsampled for the resolution of the LEPLAC DBM (900 m) by applying spatial averages.

Table 1 - Spatial Resolution of the Dataset Used in the Present Work.

Data	Spacial Resolution (m)
LEPLAC	900
SRTM15+ V 2.0	400
Multi-beam (OBS)	50
Single-beam (OBS)	100
Apha Crucis DBM	50
Pockmark Field DBM	30

Results

For this publication, the description of the results found is succinct and summarized. Therefore, it is divided into 4 sub-items: *Statistical Summary of the Analyzed Bathymetries*; *Artifacts Identification*, *Update and Reassessment of the LEPLAC DBM* and *Advances Brought by the LEPLAC DBM to the Southeastern Margin of Brazil*.

Statistical Summary of the Differences between the assessed DBMs and the reference data

The statistical summary and their respective multiseries plot of uncertainties between analysed DBMs and reference data are shown in Table 2 and Figure 3. The values of central tendency close to zero show that both the LEPLAC DBM and the SRTM15+ V 2.0 DBM are well suited to the reference data. The presence of spurious data in the LEPLAC DBM is evidenced mainly by the minimum discrepancy value (-310.9%) and the high dispersion measurement "range" (328.2%).But also, relatively high standard deviation and RMS (17.8% and 27.7%, respectively) suggests that the discrepancies are somehow heterogene in relation to the trend measures central.

The multiseries plot shows that the dispersion measurements of the LEPLAC DBM are highly influenced by the presence of few outliers. Despite the uncertainty of maximum magnitude of the SRTM15+ V 2.0 is lower than the observed for the LEPLAC DBM, the uncertainties of the first surface are more heterogene than the second, presenting more times uncertainties of intermediate magnitude.

The updated LEPLAC DBM statistical summary and the multiseries plot of the uncertainties sample indicates a consistent improvement in these parameters, achieving superior results compared to the other DBMs.

Table 2 - Statistical Summary of the Vertical Uncertainties between the analyzed DBMs and reference data, in percentage.

"n" = 2298	Reference – LEPLAC (%)	Reference – Updated LEPLAC (%)	Reference – SRTM15+ V 2.0 (%)
Minimum	-310.9	-55.7	-139,1
Maximum	17.3	18.75	28.6
Average	-2.0	0.9	-2.5
Median	-0.4	-0.3	-0.3
Mode	0	0	0
Standard Deviation	19.2	4.95	16
Range	328.2	74.5	167.7
Root Mean Square	27.7	5.0	16.14

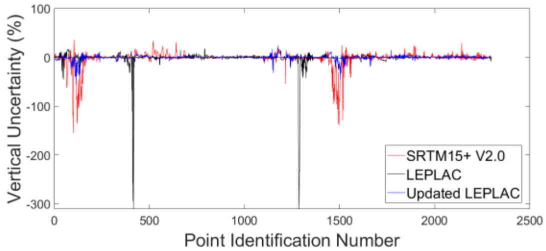

Figure 3 - Multiseries Plot of the Samples "LEPLAC Vertical Uncertainty", "Updated LEPLAC Vertical Uncertainty" and "SRTM15+ V 2.0 Vertical Uncertainty", in percentage of the reference data depth.

Artifacts Identification

The map identification of the spurious depth regions was possible mainly due to the analyzes of the Vertical Uncertainty Map and the Bathymetric Profile Graphs, shown in Figures 4 and 5.

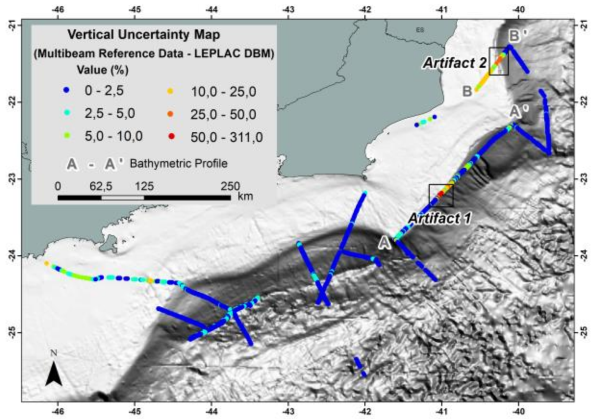

Figure 4 - Vertical Uncertainty Map of the LEPLAC DBM and identified Artifacts

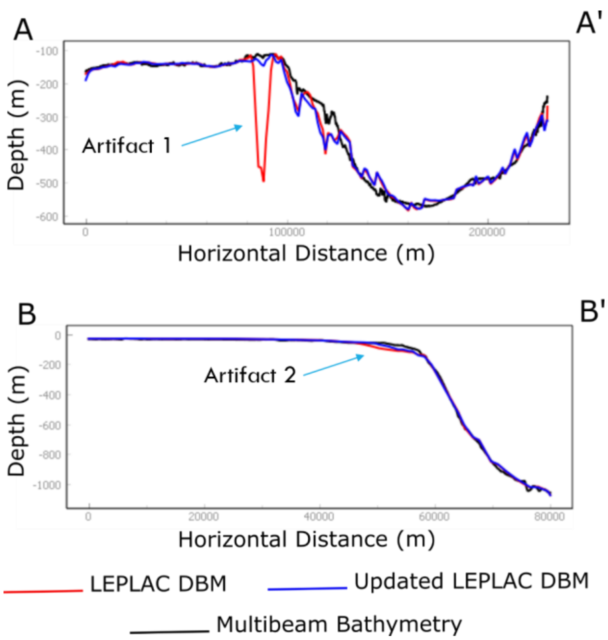

Figure 5 - Bathymetric Profiles showing Artifacts 1 and 2 in the LEPLAC DBM

Update and Reassessment of the LEPLAC DBM

After communicating the existence of the two possible artifacts in the LEPLAC DBM to DHN, they investigated and confirmed their existence. A new 1000 x 1000 m spatial resolution grid was generated containing, in which in addition to artifact correction, some new input data from acoustic soundings were also used.

The reassessment of the Updated LEPLAC DBM showed significant improvement in the region analyzed by the reference data, as shown in the Bathymetric Profile Graphs shown in Figure 6 and Difference Surface Map shown in Figure 7.

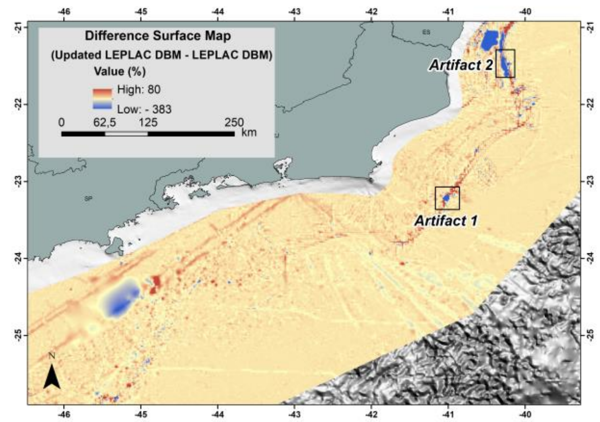

Figure 6 - Difference Surface Map between the Updated and the former LEPLAC DBM.

Advances Brought by the LEPLAC DBM to the Southeastern Margin of Brazil

LEPLAC DBM showed better qualitative and quantitative indicators in all tests performed, compared to the SRTM15+ V 2.0 DBM. For this reason, it was taken as a reference, from which the SRTM15+ DBM was subtracted, resulting in the Difference Surface Map (Figure 7).

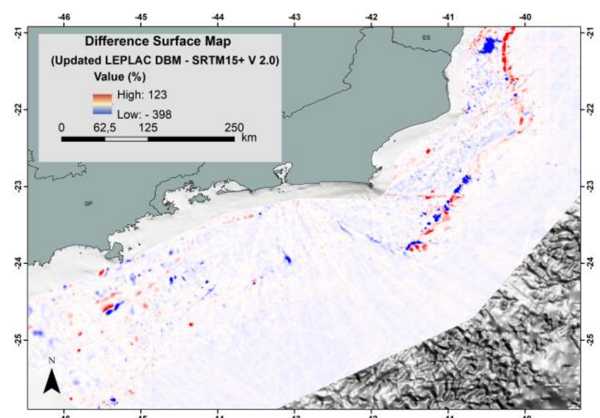

Figure 7 - Difference Surface Map between the Updated LEPLAC and SRTM15+ V 2.0.

The results show negative differences of more than 380% and positive differences of more than 80% between the two surfaces. The DBM SRTM15+ V 2.0 shows up with numerous linear artifacts from oversampling of acoustic sounding data, compared to depths from inversion of altimetric radar data in adjacent areas. These artifacts have depths close to 60 m and are distributed throughout the study area. This analysis demonstrates some of the greatness of the advances for Brazilian marine cartography arising from the publication of the LEPLAC DBM in 2019, the result of decades of joint effort by several Brazilian institutions, under the tutelage of the DHN. Furthermore, it demonstrates the importance of promoting long-term strategic scientific projects to achieve solid results.

Conclusions

The application of the Recommended Workflow for Analysis of Bathymetric Surfaces managed to identify two specific artifacts, in the region of the shelf break, which were immediately corrected by LEPLAC team. The results and experience were positive and of interest of both parts, university and the LEPLAC team.

Considering the extension of the Brazilian continental margin, the high cost and difficulties of acquiring new acoustic data, and the intensive volume of acoustic bathymetry data collected annually by universities, the authors consider that this type of interaction must be encouraged and could happen more often, beneficing both sides.

Acknowledgments

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